Geochemical analysis of Late Classic and Post Classic Maya marketplace activities at the Plazas of Cobá, Mexico

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Lines of evidence for ancient exchange plazas may include trade routes and trade artifacts, urban open space near public structures, and rock alignments denoting market stalls, but regular patterns in soil chemical concentrations also point to marketplace use. We applied geochemical and geospatial analysis of the floors of the main Plaza of Group B and Plazas A, H, and J of Group D at Cobá, Mexico, to discover the chemical residues of phosphorus (P) and metals associated with the exchange of foodstuffs and mineral workshop items that may have been marketed there. The patterns of chemical residues in the floor of the Group B Plaza suggest ritual activities while the linear, parallel patterns of elevated Mehlich phosphorus and chelate extractable zinc concentrations in Plaza A support the hypothesis of market exchange at that location. Plaza H is associated with several Postclassic buildings, including the Pinturas Structure D-33. During the Postclassic period, Cobá had lost much of its population, though chemical residues from Plaza H are congruent with marketing. We argue that Plazas A and H were not permanent marketplaces but rather multi-purpose locations that also hosted large ceremonies.

Keywords: phosphorus (P), trace elements, portable x-ray fluorescence (pXRF), Maya economy

Introduction

This paper attempts the difficult task of identifying an ancient Maya marketplace at the site of Cobá, Quintana Roo, Mexico (FIG. 1). Archaeologists working in central Mexico, where the ethnohistoric sources strongly attest to the existence of marketplaces, have often considered the role of markets in Prehispanic economies (Blanton 1983; Feinman and Nicholas 2004, 2010; Garraty 2009; Hirth 1998, 2009; Smith 2010; Stark and Ossa 2010; Stoner *et al.* 2008). A variety of approaches to recognizing market activities have emerged from this body of work. Hirth (1998) names several approaches, such as the "contextual" approach, which focuses on the identification of features (large cities, craft specialists) that demand the efficiency of exchange provided by a market; the "distributional" and "spatial" approaches, which examine the distribution of goods at the level of the site and the region, respectively (Garraty 2009; Hirth 2009; Hutson *et al.* 2010; Masson and Freidel 2012; Minc 2006); and the "configurational" approach, which attempts to identify the specific locations where markets took place (Dahlin *et al.* 2007; Hirth 1998). A fifth approach, Stark and Garraty's (2010) "production-distribution" approach, infers markets by assessing the logistics necessary to move products from producers to consumers.

The present study uses the configurational approach. Our objectives were to geochemically analyze gridded soil samples, to plot chemical concentrations geospatially, and to perform statistical analysis that could better elucidate patterns of P and trace elements within centrally located and easily accessible plazas at Cobá. A key aspect to the research was to map large and small-scale architecture in the configuration of the suspected marketplace areas to relate the data to other lines of evidence. In 2010, the west plaza of Group B and Plaza A of Group D were sampled to identify areas of high phosphorus and trace element concentrations (FIG. 2). In 2012, samples were also obtained from Plazas H and J of Group D, located to the east and west, respectively of the Pinturas Structure D-33 (FIG. 2). Patterns of high P and trace elements were analyzed to compare with previous patterns of marketplaces found in other Maya sites. A better understanding of the type of activities that could have taken place in

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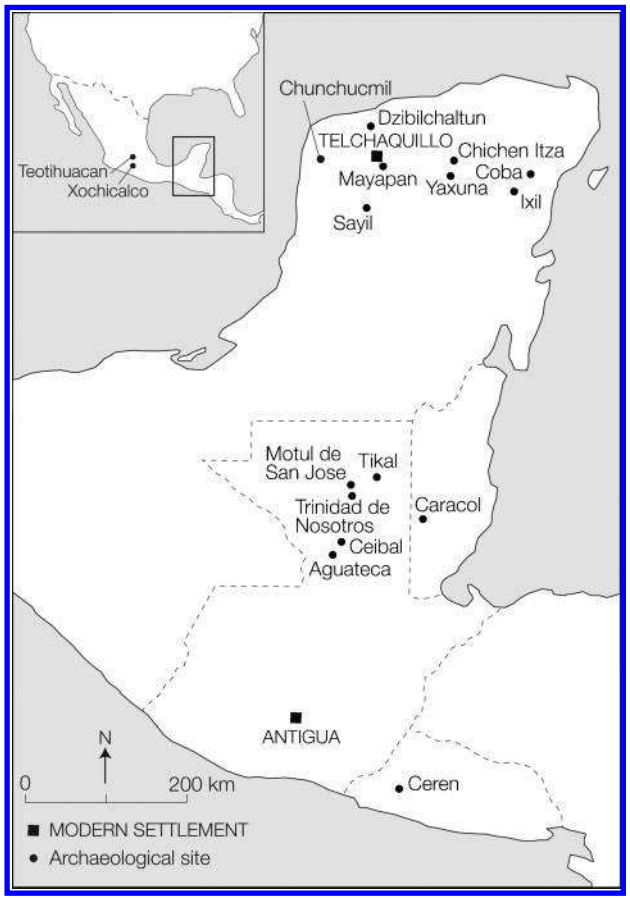

Figure 1 The location of Cobá, Quintana Roo, Mexico and other archaeological sites and modern settlements mentioned in the text.

these ancient Maya sites was acquired. In addition to discussing candidates for market locations, this study also uses data from Cobá to address the question of frequency, intensity, and context of markets. A wave of recent publications has invigorated the study of markets in ancient societies, casting off the long-standing influence of Karl Polanyi's notion that premodern economies were dominated by redistribution as opposed to commercialization (Blanton and Fargher 2010; Dahlin *et al.* 2010; Feinman and Garraty 2010). This work has helped spur a movement away from the question of whether or not marketplaces existed at large cities like Cobá and toward questions of how marketing articulated with other aspects of economy and society. In particular, we consider a spectrum of marketing contexts, ranging from frequent markets in dedicated spaces to less frequent markets held in conjunction with pilgrimages and other religious events.

Background on Markets in Mesoamerica

There is rich historical documentation of the existence of markets in many parts of Mesoamerica. For example, the marketplaces of the Aztecs, located 800 km to the west of the Maya area, greatly impressed Spanish conquistadors when they arrived in Central Mexico in 1519. Often-quoted letters by Cortés (1962), the leader of the conquistadors, and Díaz del Castillo (1956), a foot soldier, depict with

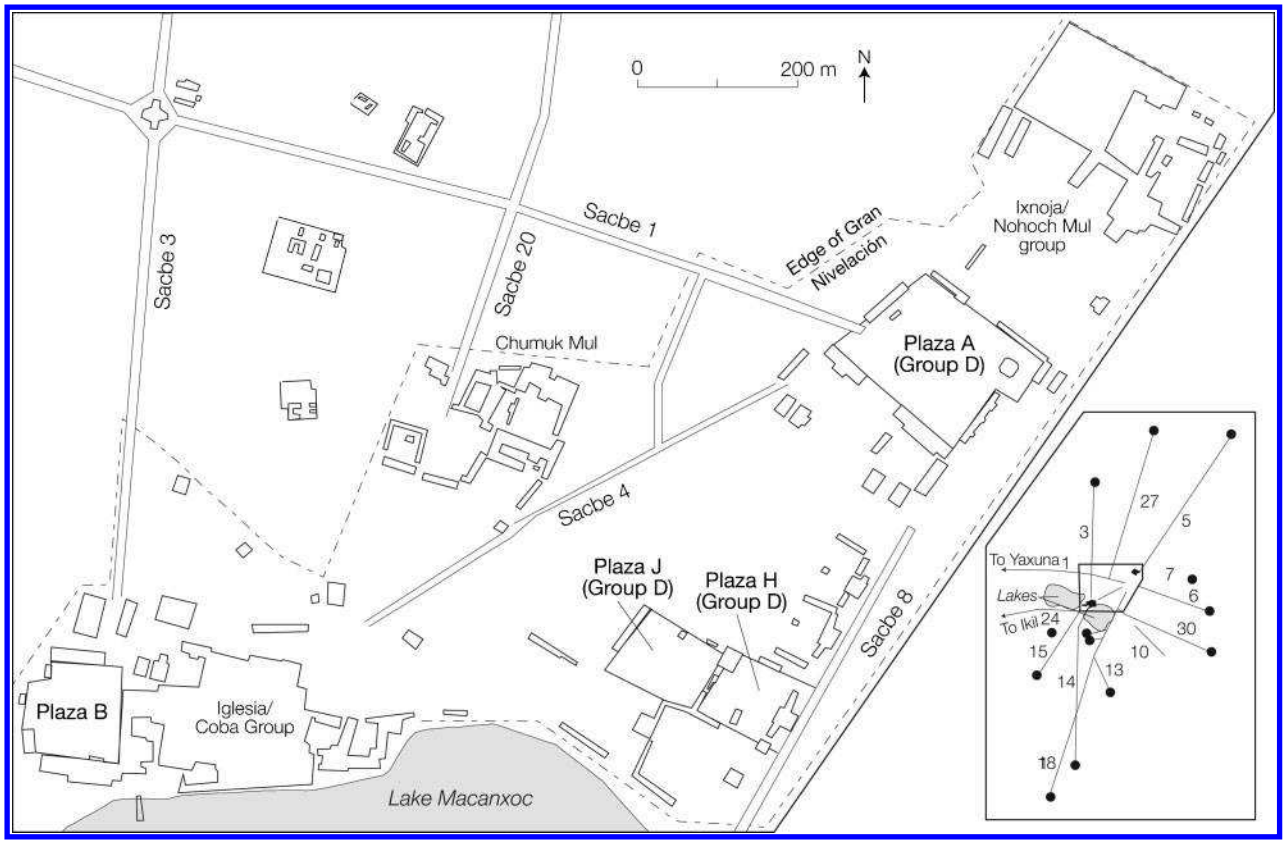

Figure 2 Map of the site center of Cobá. The locations of Plazas B, D, and Pinturas are shown. The sacbeob at Cobá are shown in inset. The map is adapted from Folan *et al.* 1983.

great detail what the marketplaces looked like. Both Cortés and Castillo were astonished by the order and control of the market, as well as with the quantity and variety of items sold (Hirth 2009). López de Gómara (1966), another conquistador, also shared his amazement at the size of the marketplace, daring to estimate that it could hold 100,000 people, while Torquemada (1943) and native Aztec informants (Sahagún 1979) recorded peculiar marketplace transactions, customs, and manners. Though such descriptions of marketplaces are scarce in the Maya area, other evidence from the contact period does suggest the existence of marketing among the ancient Maya. For example, Bishop Diego de Landa stated in his 16th century account of Yucatan that "the occupation to which [the Maya] had the greatest inclination was trade" (Tozzer 1941: 94). Susan Wurtzburg (1991: 94–97) notes the existence in Yucatec Maya of the word *k'iwik*" (or kiuik) which can be translated as "market," "fair," or "where one buys or sells." Maya dictionaries contain words for merchants, such as: *pplom* for "professional merchants," and *ah' pplom yoc* for "traveling merchants" (Roys 1939: 61). Furthermore, the protohistoric and historic long distance Maya traders had their own patron deity, Ek Chuah, which may be a late version of the Classic period God L (Taube 1992: 79–88). Finally, the Maya exported goods such as salt, honey, cotton, and cacao to markets in other parts of Mesoamerica during the Postclassic, demonstrating an engagement of market-based economies (Dahlin *et al.* 2007: 367).

Despite these Contact-era scraps of evidence for Maya marketing, ancient Maya marketplaces have not received as much attention as markets in central Mexico. Initially, neglect arose from the notions that key preconditions for market exchange—ecological diversity, large cities—were thought to not exist (Sanders and Price 1968). Even though research in the Maya area over the last half century has confirmed the presence of ecological diversity (Fedick 1996) and large cities (e.g., Tikal [Carr and Hazard 1961], Dzibilchaltun [Kurjack 1979], Chunchucmil [Magnoni *et al.* 2012]), the notion of markets has been slow to catch on, in part because of the application of a typology of cities (regal ritual, administrative, or mercantile) developed for the old world (Fox 1977). Fox defined mercantile city in a way that allows some researchers (e.g., Sanders and Webster 1988) to suggest that no Maya cities were mercantile. Yet even if Maya cities find a better fit in Fox's "regal-ritual" category (Chase *et al.* 1990), this should not mean that markets had no role in Maya cities. Indeed recent research has provided support for markets in several areas of the ancient Maya world (Braswell 2010; Dahlin *et al.* 2007; Dahlin *et al.* 2010; Halperin *et al.* 2009; Masson and Freidel 2012; Chase and Chase 2014).

Although the scant ethnohistoric evidence does not address the question of the context, intensity, or periodicity of ancient Maya markets, archaeological work suggests a spectrum from year-round markets at large sites where commerce was central, such as Chunchucmil, Mexico (Dahlin *et al.* 2007), to occasional markets at small sites where farming served as the backbone of the economy, such as Motul de San José, Guatemala (Bair and Terry 2012). At Chunchucmil, market stalls marked with stone alignments suggest year-round trade in a space dedicated exclusively to commerce. Though six large temples are located within about 250 m of the central market, each of these temples was blocked off from the market by a variety of barriers and spaces, suggesting that marketing and large-scale rituals were decoupled (Dahlin *et al.* 2007). At Motul de San José, which lacks permanent market stalls, the potential market is located in association with the largest temples at the site (Bair and Terry 2012), suggesting that marketing may have taken place as part of religious pilgrimages or grand ceremonial events (Freidel 1981: 378; Halperin *et al.* 2009; Plattner 1989: 171). The advantage of coupling markets with large, periodic, communal fairs and ceremonies is that many people are in one place at one time. Such a concentration of potential buyers and sellers can "reduce the time and effort associated with locating and procuring resources, provide access to a wider array of goods… and permit individuals to combine and engage in multiple different exchanges in a short period of time" (Hirth 2010: 236). Marketing can therefore occur on a spectrum, with frequent markets in dedicated spaces at one end of the spectrum and less frequent markets held in conjunction with pilgrimages and other religious events at the other end. In this paper, we use the configurational approach to assess the question of where Cobá, a massive city in the northeastern corner of the Yucatan peninsula that reached its apex during the Late Classic Period, fits on the spectrum.

The Configurational Approach

The configurational approach attempts to identify the specific locations where markets took place. This is difficult because, with the exception of one possible site (Calakmul, where murals in Structure Sub 1-4 of the Chiik Nahb complex depict a series of people with hieroglyphic labels that could be interpreted to suggest they are marketing items such as salt, clay pots, and maize gruel) (Carrasco Vargas *et al.* 2009), there are no texts, paintings, or other representations that announce the presence of a marketplace. Another challenge of this approach is that most items exchanged at a market would be consumed elsewhere. Thus, such items do not leave any trace at

the market itself. Those items that were most likely consumed at markets, such as food, were perishable, subject to decay in the warm, humid conditions of Mesoamerica, and therefore almost certainly not preserved as macro-artifacts (Cavanagh *et al.* 1988; Dahlin *et al.* 2010; Middleton *et al.* 2010; Wells 2004). Therefore, in this paper we attempt to identify ancient markets by leveraging three lines of evidence: accessibility, traces of small-scale architecture sometimes located within markets, and soil geochemical signatures imprinted by marketplace activities (Dahlin *et al.* 2007; Dahlin *et al.* 2010; Hirth 2009; Wurtzburg 1991). In regards to accessibility, marketplaces should be located in large plazas that have multiple unrestricted (or minimally restricted) entrances and are easy to get to. Being easy to get to means being centrally located (a location that minimizes the distance from the maximum number of households), but also includes being linked to the rest of the settlement (and perhaps other settlements in the region) by main roads and causeways. Insofar as centrality of location means being located at the core of a settlement, markets are likely to be physically close to the kinds of large structures (temples, palaces, range structures) that also populate the cores of large sites. For the Aztec, Kurtz (1974) has argued that large temples symbolically communicated the power of the Aztec state to potential miscreants in the nearby markets. Yet, as in the case of the Chunchucmil market described above, large architecture and markets may have been functionally decoupled. Another characteristic to identify marketplaces is the immediacy to water wells (Bair 2010; Dahlin *et al.* 2007; Dahlin *et al.* 2010; Wurtzburg 1991). Some studies that relied on accessibility, among other lines of evidence, in order to recognize marketplaces include Teotihuacan (Millon 1973), Xochicalco (Hirth 2000), Chichen Itza (Ruppert 1943), Caracol (Chase 1998), Chunchucmil (Dahlin 2003), Sayil (Wurtzburg 1991), and Cobá (Folan *et al.* 1983).

The second line of evidence, small-scale architecture, includes features such as aisles, stalls, and corridors, where vendors displayed their goods and through which buyers walked (Beals 1975; Feldman 1978; Warner 1976; Wolf 1959). The Chiik Nahb complex at Calakmul contains 10 north-south rows of low buildings with aisles in between them (Carrasco Vargas and Cordeiro Bacquiero 2012: fig. 2). Not all markets need such architecture, as many vendors at contemporary indigenous Mesoamerican markets simply sit with their wares spread on the ground. In cases where market stalls are constructed, such stalls can be very difficult to identify archaeologically. Though some stalls were built with non-perishable stone alignments, such as those at Chunchucmil (Dahlin *et al.* 2007), others may have been built with nothing more than canopies and posts which could have been removed from the plaza at the end of the day. Even if such canopy-and-post stalls were left in place overnight, they would likely be removed during site abandonment (Manzanilla 1996) and their most permanent architectural features, postholes, are unlikely to preserve in tropical soils with high bioturbation.

The third line of evidence is developed by analyzing the geochemical signatures in surface soils. It is understood that marketplaces generated a great deal of organic waste that would be assimilated into the plaza floors, thus increasing the chemical concentration of certain elements. Chemical compounds and their associated human activity that produces them have been reported in earlier studies, including: phosphorus (P) with food preparation, consumption, and disposal (Terry *et al.* 2000); sodium (Na) and potassium (K) with the generation of ash in cooking hearths (Middleton and Price 1996); along with iron (Fe) and mercury (Hg) compounds with the utilization of pigments in rituals (Wells *et al.* 2000). The elements that are being reported in this study are P, Fe, manganese (Mn), zinc (Zn), and copper (Cu), since evidence has linked these respective elements to middens (garbage disposal sites), burials, household contexts, and activities of ceremonies and feasting (Bair 2010; Barba *et al.* 1996; Coronel *et al.* 2011; Dahlin *et al.* 2007; Dahlin *et al.* 2010; Fernández *et al.* 2002; Manzanilla and Barba 1990; Parnell *et al.* 2001; Parnell *et al.* 2002a; Parnell *et al.* 2002b; Terry *et al.* 2000; Terry *et al.* 2004; Wells 2004).

The recent development of geochemical methods to use as one line of evidence to identify marketplaces in the Maya area will aid in the discovery of ancient systems of economic exchange. The study and analyses of geochemical traces of phosphate and trace elements persisting in soils and floors have proven to be reliable in the identification of ancient activity areas that have been related to marketplaces. As organic materials were processed, consumed, and disposed of, the phosphate and trace element constituents released from the organic matter became fixed in the surface soil (Barba 1986; Barba and Ortiz 1992; Middleton 1998; Middleton and Price 1996; Parnell *et al.* 2001; Terry *et al.* 2000). Fixed forms of P are very insoluble and resist oxidation, reduction, and leaching (Holliday and Gartner 2007; Wells 2004). As for the nature of P, it is a fundamental constituent of living tissues (in the form of nucleic acids, phospholipids, nucleotides, etc.) (Sanchez 2007), is present in products that households use (wood, plants, bones, meat, etc.) (Middleton *et al.* 2010), and its concentration in soils can be increased as organic materials such as plant and animal products are consumed and disposed of. Trace

elements also contained in foodstuffs can accumulate in the soils and floors of activity areas. Metallic residues from the crafting of stone and mineral pigments for painting are also fixed in soil surfaces (Holliday and Gartner 2007; Parnell *et al.* 2002a; Parnell *et al.* 2002b; Wells *et al.* 2000). The use of appropriate chemical extractants can solubilize portions of an anthropogenically deposited and soil adsorbed element for quantitative analysis. Total elemental analyses provide information on human activities, but the natural mineral constituents of soil and floor particles may overwhelm the trace levels of element deposited by human activities (Parnell *et al.* 2002a; Coronel *et al.* in press).

When extractable P and trace metals are present in higher concentrations compared to the natural background levels of the soil or floor materials, this could indicate areas where activities centered on foodstuffs or work with mineral materials took place. Pathways and plazas that were likely swept clean of organic materials or other types of waste have shown low P and trace element concentrations (Bair 2010; Parnell *et al.* 2002a; Terry *et al.* 2004; Wells 2004).

The presence of extractable P in soils and floors at elevated concentrations has been adopted as a proxy for ancient food preparation, consumption, and disposal areas. Other minerals, such as chelate extractable Zn, are often correlated with P concentrations at these activity areas (Dahlin *et al.* 2007; Bair and Terry 2012; Coronel 2011; Bair 2010). Several studies of chemical analysis of Maya activity areas have provided evidence of the effectiveness of stucco floors in fixing chemical residues that are byproducts originated from repeated activities (Barba 1986; Barba *et al.* 1987; Barba and Manzanilla 1987; Manzanilla 1996; Ortiz and Barba 1993; Wells 2004). Plastered, stucco floors provided a clean slate to imprint a geochemical signature by the inhabitants of the sites, since stucco floors are fairly homogenous and naturally low in P concentration (Bair 2010; Barba *et al.* 1987; Holliday and Gartner 2007; Manzanilla 1996; Middleton *et al.* 2010). Furthermore, P compounds bind easily with a calcareous soil matrix, creating insoluble P compounds (Bair 2010; Barba *et al.* 1996; Holliday and Gartner 2007).

Study Area

The ruins of Cobá are located in the northeastern area of the Yucatan Peninsula, in the municipality of Chemax (FIG. 1). The site was occupied from about 100 B.C.–A.D. 1500. Parts of the ruins are within the boundaries of the present-day community of Cobá, in the state of Quintana Roo. The Cobá area is distinguished by limestone karst topography, with a landscape spotted with outcrop bedrock projections, large lakes, as well as small, linear depressions (Folan *et al.* 1983; Wilson 1980). The average elevation is 20 masl. Cobá's nucleus is nestled among five freshwater lakes. Such lakes are extremely rare in the northern Maya lowlands. Soils encountered in the plazas at Cobá were formed from highly weathered stucco and plaza fill. Outside the plazas, most soils are shallow but high in organic matter derived from forest vegetation and high in carbonate from the limestone parent materials.

Cobá is a prime candidate for the study of marketplaces because of its large size and high settlement density. Models of ancient economies predict that marketplaces should be found in massive urban centers. Such nucleated cities favor marketplace exchange because they contain a large portion of people who do not produce food, e.g., elites, craft specialists, and administrators. This portion of the population depends on exchange to acquire basic staples. Central markets satisfy such a demand for exchange and also provide an efficient means for distributing goods among the dense concentrations of producers and consumers found in cities. Several studies have noted that other alternatives to markets, such as Polanyi's concept of redistribution, by which elites distribute common goods to the bulk of the population, would have been too difficult for cities of Cobá's scale (Dahlin *et al.* 2007: 364; Masson and Freidel 2012: 457; Stark and Garraty 2010).

Cobá was a massive city *par excellence*. William Folan's extensive systematic survey, one of only seven such surveys conducted at Maya metropolises, shows that the urban portion of the site covered 63 sq km. Based on the 21.3 sq km surveyed by Folan's team (1983), Kintz and Fletcher (1983) estimate that the city contained over 22,000 structures. The site reached its maximum population during the Late and Terminal Classic Periods (the Palmas and early Oro ceramic phases, between A.D. 600 and 900) (Robles Castellanos 1990). At this time, anywhere between 50,000 and 70,000 people lived at Cobá. In terms of both population and the amount of land it covered, Cobá surpassed all other sites in the northern Maya lowlands and had few peers in the entire Maya world. Within the city, a network of at least 20 raised causeways known as *sacbeob* (plural of *sacbe*: ancient plastered causeways) (Benavides Castillo 1976a) connected people from all corners of the site to plazas in the site center that would have been ideal locales for markets (FIG. 2).

The substantial amount of research conducted at Cobá (Benavides Castillo 1981; Folan *et al.* 1983; Manzanilla 1987; Navarrete *et al.* 1979; Robles Castellano 1990; Villa Rojas 1934) has also succeeded in showing that the city was a major regional capital during the Late Classic Period. The site boasts 32 stelae, i.e., erect stone slabs that are carved or painted

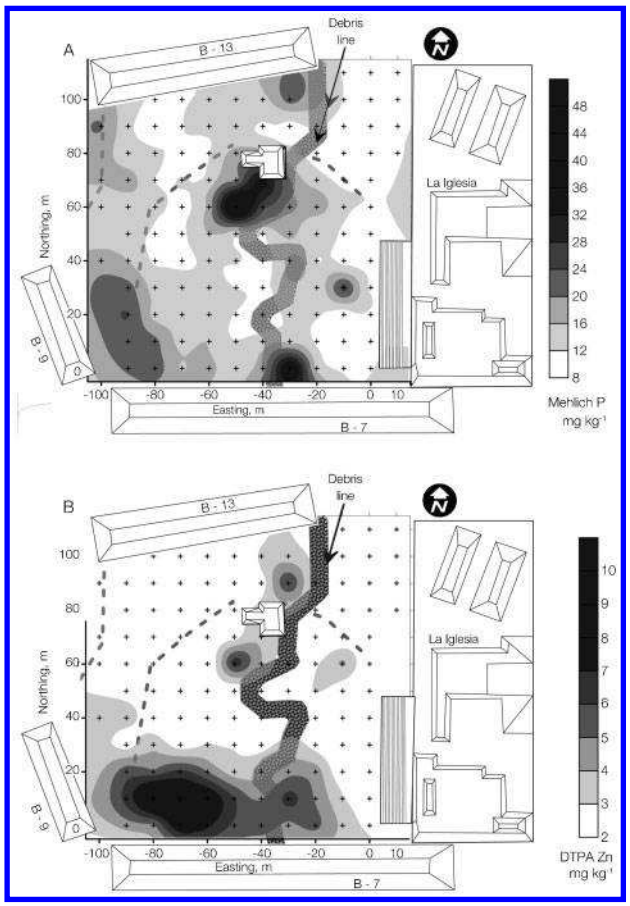

Figure 3 Cobá Plaza B with sampling locations, structures, rock alignments, and other features: (A) Mehlich extractable P concentration isopleths (mg kg^{-1}) and (B) DTPA extractable Zn concentration isopleths (mg kg^{-1}) of the plaza floor.

with images and texts that document ritual performances and the events in the lives of Cobá's kings. In addition to the sacbeob within the city, two sacbeob extend beyond Cobá's edges and connect it with Yaxuna (100 km to the west) and Ixil (20 km to the southwest) (Robles Castellano 1976; Villa Rojas 1934). The physical links to these sites, said to be subordinate allies of Cobá (Andrews and Robles Castellanos 1985), attest to Cobá's regional clout. The long distance sacbeob also likely facilitated commerce. For example Johnstone (2001; Loya Gonzaléz and Stanton 2013) argued that the people of Yaxuna traded pottery to Cobá.

ARCHITECTURE

All four plazas sampled in this study are part of the Gran Nivelación, a flat, artificially leveled, ancient terrace at the core of Cobá. Folan and colleagues (1983: 51) estimated the terrace to cover an area of approximately 1.5 sq km whereas others (Graham and von Euw 2004; Navarrete *et al.* 1979) estimate that it covers 0.64 sq km. In 2012, Brigham Young University students David Kotasek and Austin Ulmer walked with local guides around portions of the terrace perimeter. They observed an area of at least 0.68 sq km (68 ha) of the terrace, which is outlined in Figure 2. The terrace at Cobá supports a loosely interlinked array of temples, range structures, ballcourts, broad plazas, private patios, and areas of uncertain function and access. Clearly, the Gran Nivelación at Cobá is a monumental construction and was the focus of important public activities.

Plaza B (FIGS. 2, 3) is located on the west edge of what Graham and von Euw (2004) referred to as both Group B and the Cobá Group. It is also referred to by Thompson and colleagues (1932) as the Main Plaza. Plaza B is delimited to the east by a sizeable structure called El Castillo (the castle) by Thompson and colleagues (1932) and La Iglesia (the church) by Folan and colleagues (1983); this structure was excavated and consolidated in 1975. To the south, Structure B-7 runs in an east-west direction. It is nearly 100 m long × 25 m wide and up to 10 m tall. Structure B-11 is a large mound that forms the southwestern corner of the Main Plaza. To the north, Structure B-13 is 66 m long, running east-west, 25 m wide, and close to 10 m tall. This plaza is approximately 1 ha in size. The presence of a stela shrine facing Lake Cobá and stela fragments and an altar stone in front of La Iglesia prompted archaeologists to suggest that the main purpose of the area within Plaza B was ritualistic or ceremonial (Folan *et al.* 1983: 65–71; Thompson *et al.* 1932).

Plaza A of Group D (FIGS. 2, 4) is the northernmost portion of a large collection of structures to the east and north of Group B (Navarrete *et al.* 1979: 43). This plaza is delimited by long, slender buildings on all four sides: northeast (Structures D-3, D-8), northwest (Structure D-9), southwest (Structures D-11, D-14), and southeast (Structures D-7, D-4). The plaza covers 26,000 sq m (2.6 ha) and is almost completely flat with no more than 30 cm variation in the ground surface. With the exception of the northwest side, delimited by Structure D-9, the plaza is nearly rectangular. In other words, the south corner and east corner of the plaza are 3° and 1° away from being right angles, respectively, though the orientation of D-9 gives the plaza's west corner an angle of 81° and the north corner an angle 78°. This plaza contains a number of distinctive features. In the eastern end of the plaza, the inhabitants of Cobá built a distinctive pyramid (Structure D-6) whose steepness and rounded corners lend it the appearance of a cone. The structure sometimes referred to as El Cono and *Xaibe*, which is Yucatec for crossroads (Benavides Castillo 1976b), was consolidated in 1975 to a height of 14 m. It received this name because it is aligned with Sacbe 1, a 100-km long raised causeway with an eastern terminus at the west corner of the plaza. The structure measures 21 m per side and consists of three terraces (each with a stairway on the northwest side) and a solid rocky pinnacle. The stairways are nearly

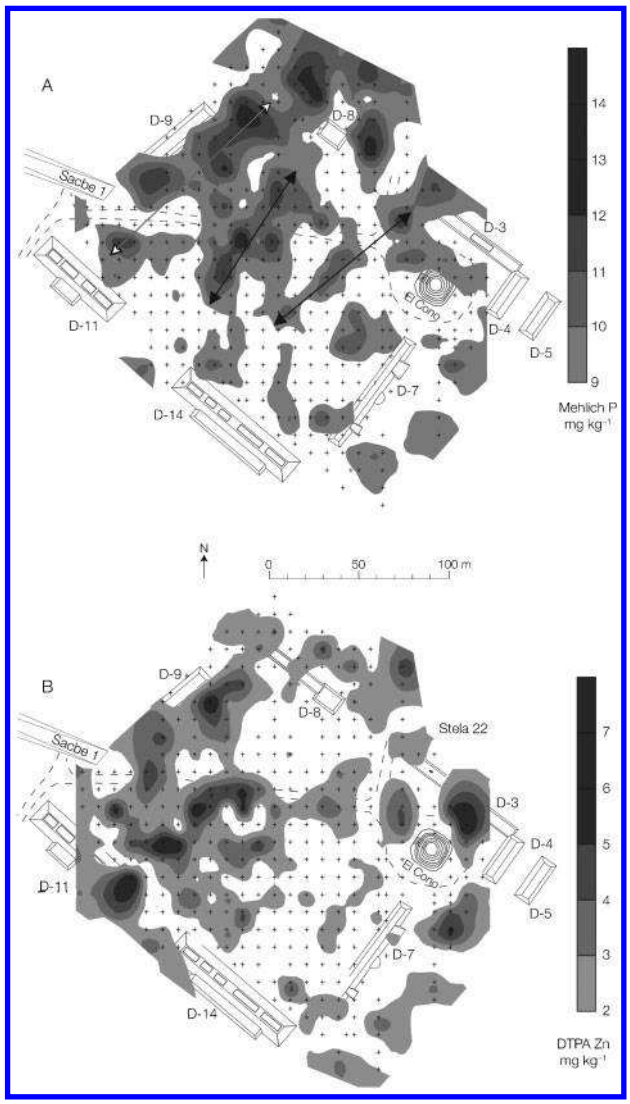

Figure 4 Cobá Plaza A of Group D with structures, Sacbe 1, and tourist paths: (A) Mehlich extractable P concentration isopleths (mg kg^{-1}) and (B) DTPA extractable Zn concentration isopleths (mg kg^{-1}) of the plaza floor.

twice as high as they are wide with a slope of 61°. The function of D-6 is still a mystery, but its pyramidal shape and high elevation suggest it served as a location for rituals that could be observed throughout the plaza. Folan and colleagues (1983) suggested that rituals were offered at El Cono/Xaibe by merchants coming in and out of the plaza. Sacbe 1, which extends westward to the large archaeological site of Yaxuna, is the longest sacbe in the ancient Maya world (Navarrete *et al.* 1979). Sacbe 1 reaches a maximum height of 2.5 m (Villa Rojas 1934: 198) and a width of 10 m. It is important to note that while Sacbe 1 starts at the boundary of Plaza A, Sacbeob 4, 6, 7, and 8 also start very close to the borders of the plaza (Thompson *et al.* 1932). The termini of Sacbeob 6 and 7 are just to the east of El Cono (Structure D-6) and the parallel Structures D-4 and D-5 which may have been a ballcourt (see below for a discussion). The terminus of Sacbe 8 is just to the south of Structure D-7, while Sacbe 4 ends to the southwest of Plaza A, also close to a ballcourt (FIG. 2). This suggests that Plaza A was a much transited location at the crossroads of several causeways.

Plaza A is also distinctive because one of the structures delimiting its southeastern edge (Structure D-4) may form a ballcourt with a parallel mound to the east (Structure D-5), outside of the plaza. The parallel mounds are about 30 m long (the exact foundation braces were not visible), and the alley is 10 m wide. Though this is a wide alley for a ballcourt of such length, the assessment of D-4 and D-5 as ballcourt structures is strengthened by the fact that the sides of the parallel buildings that face the alley are more gradually sloped than the back sides, and the surface of the walls that slope toward the alley consist of slanted facing stones that form a *talud* (an architectural style associated with the Teotihuacan culture of central Mexico). Despite being one of the most clearly delimited plazas at the site, Plaza A may have grown by the accretion of multiple different construction projects. For example, the potential ballcourt at D-4 and D-5 may have preceded or postdated other buildings on the plaza. Furthermore, Ian Graham's original map of the area (Graham and von Euw 2004) and additional mapping details gathered in 2012 suggest that the two buildings on the southwest side of the plaza (D-11 and D-14) face to the southwest, away from Plaza A, each toward its own smaller plaza. It is as if D-11 and D-14 predate Plaza A. None of the buildings on the sides of the plaza have orientations that are even remotely close to being parallel or perpendicular to Sacbe 1. This suggests that the sacbe and the other plazas were not built according to the same plan. The Plaza and its buildings have multiple phases of occupation. Whereas Sacbe 1 and Stela 22 atop Structure D-3 are Late Classic features, an addition to the front façade of Structure D-6, El Cono/Xaibe, dates to the Postclassic period. The long slender buildings on each of the four sides have different heights, suggesting a lack of centralized planning and that the final layout of the plaza was the result of the successive building episodes. The tall buildings on the south edge of the plaza (D-1, D-14) were likely part of an early construction and since only their posterior sides faced Plaza A, they functioned as boundary markers for the plaza. On the other hand, the low-lying structures on the northern side of the plaza, D-3 and D-8, may have been kept low so that people in Plaza A could still see the largest monumental complex at the site, the Nohoch Mul, to the north (FIG. 2) (Navarrete *et al.* 1979). Structure D-7 in the southeastern portion of Plaza A also shows evidence of later occupation. A semicircular foundation brace (7.8 m in diameter) with crude boulders was placed right along the middle of the eastern side of this long

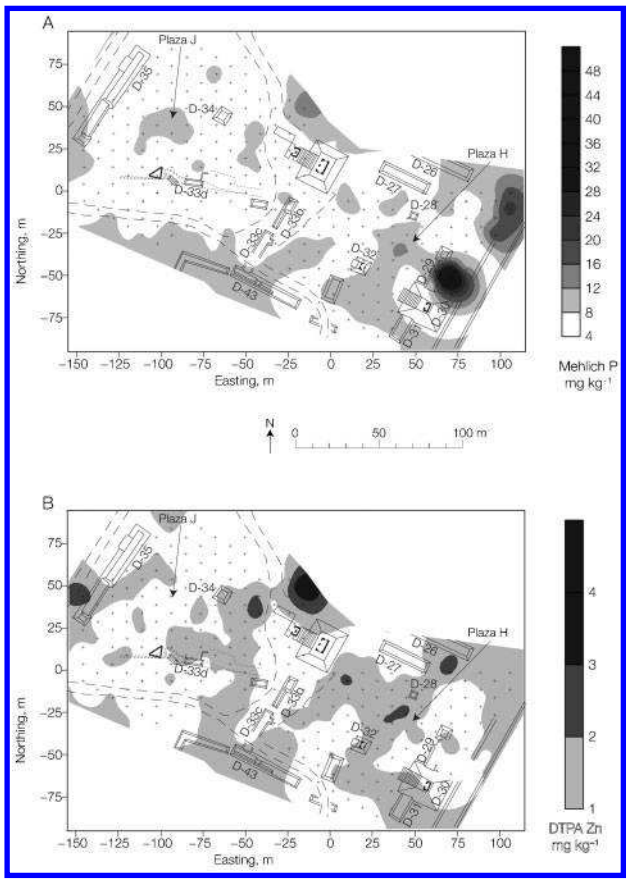

Figure 5 The structures and sacbeob associated with Pinturas Plazas H and J at Cobá: (A) Mehlich extractable P concentration isopleths (mg kg^{-1}); and (B) DTPA extractable Zn concentration isopleths (mg kg^{-1}) of the plaza floor.

structure; it is likely that simple construction was a later addition, as already suggested by Navarrete and colleagues (1979).

Plazas H and J of Group D are located to the east and west of the Pinturas pyramid (D-33) (FIGS. 2, 5) (Navarrete *et al.* 1979: 44), near the southeast corner of Cobá's great terrace. This is the only plaza sampled in this study with a substantial Postclassic period occupation. Postclassic ceramics dominate the Pinturas area (Robles Castellanos 1990: 46). At the top of the stepped platform, Structure D-33 (FIG. 5), sits a vaulted temple with an inset lintel and one column—a distinctive style in use during the Postclassic along the East Coast of Yucatan (Lombardo de Ruiz 1987: figs. 27–31). The walls of this temple contain several stucco layers covered in polychrome Codex style paintings dating to A.D. 1100–1400 (Lombardo de Ruiz 1987: figs. 32–43; Fettweis-Vienot 1980, 1987; Peniche Rivero and Folan 1978). Of significance is the elaborate stucco frieze partly preserved on the molding of the exterior façade, which according to Fettweis-Vienot (1980, 1987) refers to a sacrificial ritual in front of the god Itzamna. A small, smoke-darkened oratory sits at the base of the staircase on the west side, which contains a bench, fragments of a stela (reset from its original location), a round altar, a stone phallus, and stone sphere (Peniche Rivero and Folan 1978). The exterior and interior walls of this oratory were also covered by several layers of painted stucco and each layer was adorned with polychrome paintings (Lombardo de Ruiz 1987: figs. 45–60). According to Peniche Rivero and Folan (1978) in one of those layers on the interior wall, hieroglyphic elements of the Ek Chuah, the god of commerce, can be appreciated. Fettweiss-Vienot (1980, 1987) who carried out a detailed study of the murals of Las Pinturas does not mention any reference of Ek Chuah but she mentions that they are poorly preserved on this building. Immediately to the west of D-33's west facing stairway lie 13 small altars, a reference to the 13 Sky Gods of Maya mythology. Each altar is different in form and construction. The lower portion of a stucco figure was located in the main altar (Peniche Rivero and Folan 1978).

Plaza H (FIG. 5) is well defined, with the D-30 pyramid on the east, Structure D-27 on the north, Structure D-43 to the south, and previously unnamed structures, which we refer to as D-33b and D-33c, on the west. Structure D-30 is a stepped platform with a small East Coast style temple with an inset lintel sitting at its top and two low lying platforms extending north (connecting to Structure D-29) and south (extending towards Structure D-31). The basic layout of this structure is similar to another important Postclassic Structure, D-38, to the northwest close to Sacbe 4 and Structures D-19 and D-24 to the north, likely also dating to the Postclassic (Navarrete *et al.* 1979). In the middle of this plaza lies D-32, a small and low lying platform with a poorly preserved temple on top and two small altars in front. Plaza H covers 0.5 ha. Plaza J is less well defined, with buildings on its east (D-33, D-33b, D-33c) and west (D-35) sides and a platform in the middle (D-34). A very roughly built string of low platforms and stone rubble (labeled D-33d in the map) lies to the south of D-34, but this does not appear to have been planned as a formal edge of the plaza.

Methodology

Ian Graham's map of the Cobá site center (Graham and von Euw 2004) guided the cutting of transects through the vegetation of the three plazas. Additional structures, paths, rock alignments, and other features in Plaza B and Plazas A, J, and H of Group D, were recorded using Magellan MobileMapper^{TM} units. Plaza A was mapped with a total station transit in 2012. Except for the contemporary paths built to accommodate tourist movement, the entire area was covered with thick forest vegetation. Grids of 10-m intervals were established over the plaza floors by means of compasses and measuring tapes. Sampling

locations were marked with flags and GPS units were used to aid in the sampling and mapping of architecture. Floor samples beneath rotted logs, tree stumps, and debris piles could be depleted of metals or enhanced in phosphorus concentration, therefore these areas were avoided. At each grid point leaf litter was removed and surface samples of the plaza floor including weathered stucco and limestone gravel were collected with a plastic trowel from the 0 to 10-cm depth. Samples were placed in WhirlPak plastic bags for shipment to the laboratory.

Phosphorus analysis

Soil P is found in different forms (soluble and labile inorganic P, organic P, inorganic P fixed to Al, Ca, or Fe compounds, etc.), and analytical methods are not able to detect these different forms simultaneously. Thus, several methods exist to analyze for the different fractions of soil P (Terry *et al.* 2000). In general, four types of P analysis have been performed in archaeological studies: chemical digestion of soil for total P concentrations, P fractionation, spot tests, and the extraction of soluble P by weak-acid or basic solutions (Holliday and Gartner 2007; Terry *et al.* 2000). Often, extractable P does not correlate to total P. This lack of correlation could be attributed to several factors; for instance, the extraction techniques solubilize only a portion of the soil P and trace metals to approximate the nutrients available for plant uptake. Total digestion with nitric and perchloric acid solubilizes all of the mineral and organic P and metal constituents that are, for the most part, neither plant available nor anthropogenic. Relative concentrations and spatial distributions of chemical residues are key to the identification of human activity areas.

The surface samples collected in the Cobá plazas were chemically analyzed at the Brigham Young University Environmental Analysis Laboratory. The air-dried, crushed, and 2 mm sieved samples (2 g) were shaken in 20 ml of Mehlich II extractant for 5 minutes, after which they were filtered through a 15-cm diameter filter paper. Then, 1 ml of the extract was dispensed into a colorimeter vial, diluted to 10 ml with deionized water, and a packet of PhosVer 3 Reagent (Hach Company, Loveland, CO) was added. Samples were shaken for one minute, and allowed to sit for four minutes for color development. Finally, the samples were measured with a Hach DR/850 Colorimeter, using the % transmittance function at a wavelength of 690 nm. Phosphorus was calculated in mg kg^{-1} by means of a standard curve developed with known P levels and multiplication by a dilution factor of 100. Detailed information about the modifications in the Mehlich II method can be found in Terry and colleagues (2000). The relative standard deviation for the control sample analyzed by the Mehlich II method was 4.4% (n=12).

DTPA analysis

Chelate extraction of metal ions from the soils and floors of ancient activity areas has the advantage of removing only small portions of the element that are solubilized from the surfaces of soil minerals and organic matter. It is likely that elemental residues produced by human activities associated with food, workshop minerals, and rituals are absorbed on the surfaces of soil and floor particles (Parnell *et al.* 2002a). The Cobá plaza samples were analyzed for extractable trace metal concentrations using the DTPA (diethylenetriaminepentaacetic acid) chelate extraction procedure developed by Lindsay and Norvell (1978). Ten grams of air dried, sieved (<2 mm) soil were extracted with 20 ml of 0.005 M DTPA solution buffered at pH 7.3. The samples were shaken for two hours, after which the extracting solution was separated from the soil by centrifugation and filtration. The concentrations of Cu, Fe, Mn, Pb, and Zn were determined simultaneously on a Thermo Inductively Coupled Plasma Atomic Emission Spectrometer (ICPAES). DTPA solution was used as a blank and one control soil sample was analyzed with each run. The relative standard deviations for the extractable DTPA elements of the analytical control soil (n=10) were 3.8% for Cu, 3.1% for Fe, 9.4% for Mn, and 5.5% for Zn. The repeated analysis of the standard soil sample shows the high reproducibility of the obtained results.

Portable x-ray fluorescence analysis

Total elemental analysis of metals in soils and floors by hand-held portable x-ray fluorescence (pXRF) has both advantages and disadvantages in geochemical analysis of ancient activities. The pXRF instrument is expensive (ca. $20,000–$40,000) but analysis is quicker and easier to perform than wet chemistry extraction or acid digestion coupled with spectrometric determination of element concentrations. The ability to perform chemical analysis by pXRF in a field laboratory has the advantage of providing results during the field season. The pXRF assay of total element content requires drying in air, crushing, and sieving prior to analysis (Bernick *et al.* 1995; Fedick 2010; Melquiades and Appoloni 2004). Another advantage of pXRF total analysis is the ability to identify the relative makeup of the floor material, whether local soils or limestone derived fill and stucco. Total calcium (Ca) content relative to total titanium (Ti), aluminum (Al), and heavy metal signatures of natural clays could help determine the type of construction materials. The major disadvantage of total elemental analysis is that the natural elemental components of soil particles and floor

materials may overwhelm the tiny deposition of elements that resulted from anthropogenic activities. Coronel and colleagues (in press) recently proposed a protocol for sample preparation and the analysis of geochemical residues in the soils and floors of ancient household and plaza activity areas. Total elemental analysis of selected metals in this study was determined with a Bruker S1 Tracer IV-SD pXRF (Bruker AXS, Kennewick, WA). The unit employs a rhodium (Rh) target x-ray tube excitation source and a silicon (Si) Pin diode detector. It is equipped with a probe window and x-ray tube that irradiates the sample and the x-rays can either scatter or be absorbed by atoms in the sample and re-radiated as x-rays of specific energy in a photoelectric effect.

The fundamental parameters analysis was standardized with the "Soils with Calcium Carbonate" calibration provided by Bruker. The calibration was developed by Bruker using 102 certified soil, sediment, and limestone standards from various sources. The calibration employed filter #1 (25 μm Ti, 300 μm Al), an excitation voltage of 45 kV, and a current of 30 μA. WhirlPak bags containing the air-dried and 2 mm sieved floor samples were placed atop the probe window, and the x-ray fluorescence signal was collected for 120 seconds.

The samples collected in this study were from anthropogenic plaza fill and weathered stucco. Natural soils of the area are not the appropriate control for constructed plaza floor samples, and so background control samples are a concern (King 2008; Wells 2004). To address this issue, previous geochemical studies have estimated background elemental concentrations by averaging the 10% of samples lowest in concentration (Bair 2010; Dahlin *et al.* 2007; Fernández *et al.* 2002; Hutson and Terry 2006; King 2008; Parnell *et al.* 2001; Terry *et al.* 2004; Wells *et al.* 2000). The plaza samples lowest in P and trace elements may represent the areas of lowest chemical enrichment by ancient human activities.

Geostatistical analysis of the element concentration data was performed using Surfer Software (Golden Software, Golden, CO) and ArcGIS. Isopleth maps illustrating element concentration distributions across the Cobá Plaza B, and Plazas A, H, and J of Group D were produced using a kriging model and variogram analysis. Correlation matrices were created using JMP software (SAS Institute Inc., Cary, NC) to distinguish significant relationships between various element concentrations.

Results and Discussion

Plaza B

In total, 124 surface samples were collected in Plaza B. The maximum, minimum, averages, and background values of Mehlich extractable P, DTPA extractable metals, and pXRF total metals in the floor of Plaza B are shown in Table 1. Background levels of extractable P were approximately 7.7 mg kg^{-1}.

The P concentration isopleths in Plaza B are shown in Figure 3a. The areas of elevated P were along the line of vegetative debris through the center of the plaza and most likely not related to ancient Maya activities. The site workers regularly use machetes and rakes to keep the eastern third of Plaza B free of understory vegetation to accommodate tourists at La Iglesia (FIG. 3A). P concentrations were near background levels in the eastern third of the plaza that is cleared to accommodate tourism. Phosphorus concentrations were elevated on the west side of the plaza beneath the forest canopy. Sample P concentrations were very low (4–6 mg kg^{-1}) in front of La Iglesia and other structures that delimit the east side of the plaza. P levels were elevated along the line of contemporary debris and elevated extractable P concentrations were also observed at the southern edge of the plaza in front of Structure B-7.

The background levels of DTPA extractable Zn and pXRF total Zn in the floor of Plaza B were 0.9 and 49 mg kg^{-1}, respectively. The extractable Zn concentration isopleths are shown in Figure 3b. The southern portion of the plaza in front of Structure B-7 contained the highest concentrations of extractable Zn ranging from 5–10 mg kg^{-1} at the foot of the staircase. High concentrations of extractable Zn also followed the line of debris through the center of the plaza (FIG. 3B). The patterns of total Zn levels in the plaza floor, as determined by pXRF (data not shown), were different than those of the extractable Zn. Total Zn was in excess of 100 mg kg^{-1} at the north end of the plaza in front of Structures B-13 and La Iglesia. Concentrations were lower (between 50–100 mg kg^{-1}) at the south end of the plaza adjacent to Structure B-7. This demonstrates the difference in possible anthropogenic Zn adsorbed on particle surfaces and extracted by DTPA as opposed to the total Zn content of the mineral constituents that make up the soil. There were highly significant correlations between extractable P and extractable Zn ($r=0.454^{**}$) and total Zn ($r=0.223^{*}$) (TABLE 2, * represents significance at $p<0.05$ and ** represents significance at $p<0.01$). It is interesting, however, that there was no significant correlation between extractable and total Zn ($r=0.086$). The patterns of elevated total Zn in the northern portion of the plaza floor suggested differences in the sources of stucco used to pave the ancient plaza.

DTPA extractable Fe was highest in the non-vegetated area, relatively close to La Iglesia on the east side of the plaza (FIG. 6A). The highest Fe concentration was 24 mg kg^{-1}. Extractable Fe was found in concentrations of 10–18 mg kg^{-1} close to the west side of the plaza. Clearly, some Fe

Table 1 The elemental concentration (mg kg^{-1}) maxima, minima, and averages of Mehlich II extractable P, DTPA chelate extractable metals, and pXRF total metals in the soils and floors of Plaza B at Cobá, Mexico. The background concentrations of elements were calculated by averaging the 10% of the samples lowest in concentration.

	Mehlich	DTPA	DTPA	DTPA	DTPA	DTPA	DTPA	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF
	P	Cu	Fe	Mn	Pb	Sr	Zn	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Zr
	mg kg^{-1}														
Maximum	45.2	0.777	23.06	27.20	4.262	18.228	10.614	1160	516	8895	61.9	189.0	48.4	4441	208
Minimum	0.0	N.D.	1.05	3.72	0.218	5.836	0.627	172	56	1215	39.4	44.2	12.7	1790	72
Average	15.0	0.333	9.90	15.75	0.876	11.464	2.914	527	258	3181	48.9	80.5	26.7	3045	147
STDEV	6.5	0.128	4.84	5.72	0.569	3.417	2.021	187	96	1437	3.9	31.8	6.7	496	25
Background	7.7	0.161	3.13	6.37	0.350	6.514	0.905	286	108	1494	43.0	49.0	17.1	2193	102

N.D.=not detectable.

concentrations were also high next to the debris line through the center of the plaza. Background levels of extractable Fe were approximately 3.1 mg kg^{-1} (TABLE 1). It is possible that contemporary, maintenance activities with iron-based machetes and rakes contributed to these elevated extractable Fe levels on the east side of the plaza. Terry and colleagues (2004) reported high Fe levels in the earthen floor of the contemporary guard's house at Aguateca, Guatemala; the high Fe concentrations were aligned with the location of benches where the park guards sharpened their machetes.

The total Fe concentration isopleths of the plaza floor are shown in Figure 6b. Total Fe levels were more than two orders of magnitude higher than the levels of chelate extractable Fe, and the patterns of high and low concentration of the two forms of Fe were very different (FIG. 6A, B). The greatest extent of total Fe enriched plaza floor was on the west side of the plaza beneath the forest growth. Both extractable and total Fe levels were elevated in samples from the western portion of the plaza. In contrast to the high extractable Fe levels of the cleared east side of the plaza, total Fe concentrations were relatively low in the eastern half of the plaza where undergrowth and leaves are routinely cleared with machetes and rakes. The correlation between extractable and total forms of Fe was very low (0.195) (TABLE 2). The source of extractable and total Fe enrichments in the western portion of the plaza floor was likely from anthropogenic sources of mineral pigments and paints used on the structures as well as ritual use of pigments. High levels of extractable Fe on the east side of the plaza were likely from modern iron implements used to clear the plaza to accommodate tourist visits. It is known that iron weathers to less soluble crystalline forms over long periods (Raiswell 2011). There is a significant negative correlation between extractable P and extractable Fe ($r=-0.403^{**}$) but no significant correlation between extractable P and total Fe.

The maximum concentrations of chelate extractable and total Mn were 27 and 516 mg kg^{-1}, respectively (TABLE 1). Background levels of Mn were 6.4 and 108 mg kg^{-1}, respectively for extractable and total forms in the plaza floor. Concentrations of both forms of Mn were highest on the west side of the plaza beneath the forest canopy. Extractable Cu was barely detectable at less than 1 mg kg^{-1} and total Cu ranged from 62–39 mg kg^{-1} (TABLE 1). There were positive correlations between extractable Cu and extractable Mn, total Fe, and total Mn (TABLE 2). Manganese, Cu, and Fe are important micronutrients contained in plant and animal tissues. Both Mn and Cu are contaminant elements found in iron ores (NIST 2013: table 111.2[2]). Mineral contamination

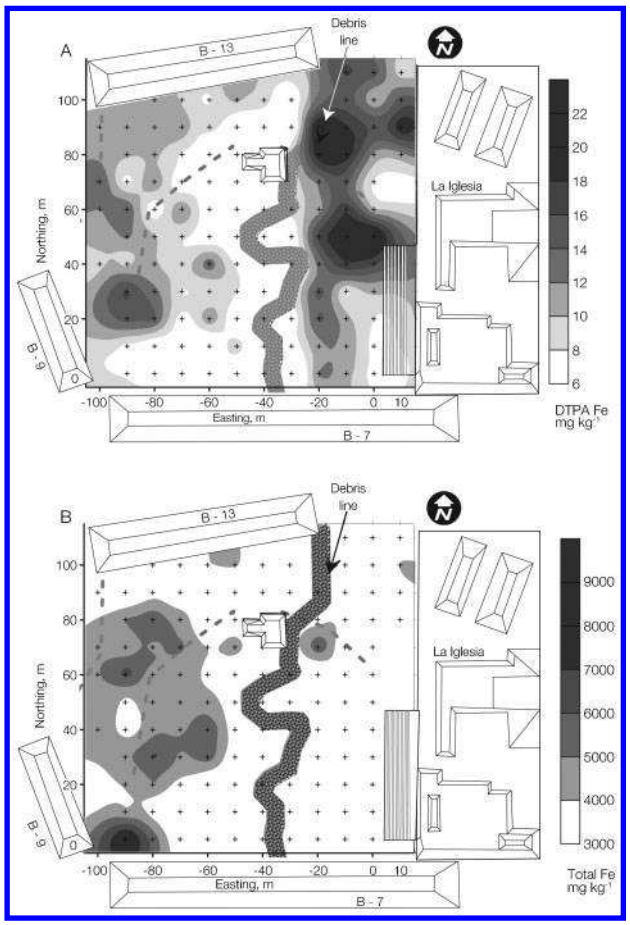

Figure 6 Concentration isopleths (mg kg^{-1}) of (A) DTPA extractable Fe and (B) pXRF total Fe in the floor of Cobá Plaza B.

of Fe based pigments was likely one of the sources of Mn, Cu, and other trace elements in the plaza floor.

Plaza A, Group D

The maximum, minimum, average, and background concentrations of extractable and total elements in the floor of Plaza A of Group D are listed in Table 3. Maximum concentrations of Mehlich II extractable P (14.7 mg kg^{-1}) in the stucco floor of Plaza A were much lower than the 45.2 mg kg^{-1}of extractable P found in Plaza B. The background P level of 7.4 mg kg^{-1} was also very low. The geospatial patterns in elevated P concentrations in the western half of Plaza A appeared linear and were parallel to Structure D-9, though one of the lines is disrupted by the presence of Structure D-10, which is paired with Structure D-9 (FIG. 4A). The samples with elevated P appeared to form three parallel lines, in a northeast direction shown as arrows in Figure 4a. These lines were perpendicular to Structures D-8 and D-11and to the path of Sacbe 1. Removal of the leaf litter and humic layer in this area of enriched phosphates revealed no stone alignments. Thus, if there were market stalls in a linear pattern, such stalls may have been temporary constructions, built entirely of perishable materials. The spatial distribution of the lines of high P concentration suggested that market aisles were

Table 2 Correlation coefficient (r) matrix of Mehlich II extractable P, DTPA chelate extractable metals, and pXRF total metal content of gridded samples from the floor of Plaza B at Cobá. Correlation significance is represented by * at $p<0.05$ and ** at $p<0.01$.

n=115	DTPA Cu	DTPA Fe	DTPA Mn	DTPA Pb	DTPA Zn	pXRF Ti	pXRF Mn	pXRF Fe	pXRF Cu	pXRF Zn	pXRF Rb	pXRF Zr
Mehlich P	**0.405****	**−0.487****	**0.315****	**−0.071**	**0.454****	**−0.050**	**0.261****	**0.010**	**−0.127**	**0.223***	**−0.122**	**−0.670****
DTPA Cu		−0.252*	0.790**	0.087	0.687**	0.303**	0.590**	0.387**	0.186	0.136	0.295**	−0.593**
		DTPA Fe	−0.021	−0.112	−0.329**	0.234*	0.161	0.195*	0.024	−0.094	0.247*	0.486**
			DTPA Mn	−0.038	0.354**	0.501**	0.829**	0.599**	−0.024	0.087	0.499**	−0.460**
				DTPA Pb	0.239*	−0.097	0.003	−0.091	0.236*	−0.212*	−0.031	0.048
					DTPA Zn	−0.178	0.259**	−0.144	0.247*	0.086	−0.179	−0.515**
						pXRF Ti	0.659**	0.940**	0.059	0.193	0.860**	−0.091
							pXRF Mn	0.743**	0.012	0.125	0.605**	−0.382**
								pXRF Fe	0.033	0.171	0.907**	−0.119
									pXRF Cu	0.099	0.095	0.085
										pXRF Zn	0.101	−0.212*
											pXRF Rb	0.121

established and foodstuffs were prepared and traded in this area. A similar pattern where high P levels were found aligned with structures and a sacbe were reported at the Central Plaza of Chunchucmil (Dahlin *et al.* 2007). The spatial distribution of elevated P concentrations in Plaza A generally followed linear, parallel patterns as reported in other suspected marketplaces. For example, linear patterns of phosphate at Plaza V of Trinidad de Nosotros, Petén, Guatemala were at similar concentrations, between 10–30 mg kg^{-1} (Dahlin *et al.* 2010: fig. 12). Linear patterns but much higher P concentration have been reported in previous studies of plaza soils, such as those in Sector K of Mayapan, Yucatan (maximum P level: 335 mg kg^{-1}, average 72 mg kg^{-1}); Ceibal, Guatemala, Group A (maximum P level: 533 mg kg^{-1}, average 81 mg kg^{-1}) (Bair 2010), and the marketplace at Chunchucmil (maximum P level: 272 mg kg^{-1}, average 57 mg kg^{-1}) (Dahlin *et al.* 2010).

Plaza A floor samples with elevated extractable Zn levels were found mainly on the western portion of the plaza (FIG. 4B). The highest concentration was 7.8 mg kg^{-1} and background level was 0.8 mg kg^{-1} (TABLE 3). The correlation of extractable P to extractable Zn was weak but significant (r=0.262**). Additional areas of elevated extractable Zn were at the entrance to Sacbe 1 and under the forest canopy next to El Cono/Xaibe (FIG. 4B).

Table 4 contains the correlation matrix of Mehlich extractable P, DTPA extractable, and pXRF total elements from Plaza A. There were significant negative correlations between P and DTPA Fe (r=−0.394**), and Mn (r=−0.148*), and a positive correlation with Zn (r=0.262**) (TABLE 4). The negative correlation of P with Mn and Fe suggests that specific activities were performed in different areas of the plaza, as it was suggested for the East Palace Court (Group E) location in Ceibal, Guatemala (Bair 2010). Except for the lack of correlation between extractable Fe and Zn (r=0.070), all the correlations between the trace elements were significant ($p<0.05$). The highly significant correlation between extractable P and extractable Zn is important to note, since it has been reported in other studies that P and Zn usually correlate with each other (Bair and Terry 2009; Dahlin *et al.* 2007). For example, significant (*$p<0.05$) and highly significant (**$p<0.01$) correlations between extractable P and Zn were reported in the following studies: Antigua, Guatemala, a contemporary open-air market (r=0.407*) (Dahlin *et al.* 2007); Group P-114 (r=0.366**), Group Y-45 (r=0.412**), and Square K (r=0.720**) at Mayapan, Mexico; Central Plaza in Group A (r=0.187**) and an elite household in Group C in

Table 3 The elemental concentration (mg kg^{-1}) maxima, minima, and averages of Mehlich II extractable P, DTPA chelate extractable metals, and pXRF total metals in the soils and floors of Plaza A in Group D at Cobá. The background concentrations of elements were calculated by averaging the 10% of the samples lowest in concentration.

	Mehlich	DTPA	DTPA	DTPA	DTPA	DTPA	DTPA	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF
	P	Cu	Fe	Mn	Pb	Sr	Zn	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Zr
	mg kg^{-1}														
Maximum	14.7	2.546	50.820	50.220	6.750	29.220	7.864	5580	1573	56854	60	189	141	3841	200
Minimum	6.5	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	310	93	1724	27	42	9	229	33
Average	9.2	0.327	12.442	17.758	0.996	13.538	2.196	1438	411	10665	48	77	43	1753	107
STDEV	1.3	0.193	7.457	8.618	0.468	4.160	1.260	838	210	8948	5	24	23	798	40
Background	7.4	0.130	2.923	5.586	0.400	7.170	0.806	472	182	2934	39	51	17	671	45

N.D.=not detectable.

Table 4 Correlation matrix of Mehlich extractable P, DTPA chelate extractable metals, and pXRF total metal content of gridded samples from the floor of Plaza A of Group D at Cobá. Correlation significance is represented by * at $p<0.05$ and ** at $p<0.01$.

n=354	Cu DTPA	Fe DTPA	Mn DTPA	Pb DTPA	Zn DTPA	Ti pXRF	Mn pXRF	Fe pXRF	Cu pXRF	Zn pXRF	Rb pXRF	Zr pXRF
P Mehlich	0.042	−0.394**	−0.148*	−0.133*	0.262**	−0.424**	−0.283**	−0.377**	0.248**	0.015	−0.442**	−0.558**
Cu DTPA		0.140*	0.534**	0.492**	0.341**	0.175**	0.149*	0.185**	0.063	0.083	0.233**	0.026
Fe DTPA			0.359**	0.209**	0.070	0.222**	0.125*	0.190**	−0.124*	−0.142*	0.218**	0.590**
Mn DTPA				0.607**	0.397**	0.339**	0.263**	0.290**	0.003	0.056	0.357**	0.225**
Pb DTPA					0.313**	0.366**	0.325**	0.360**	−0.021	0.160**	0.385**	0.133*
Zn DTPA						−0.187**	−0.159**	−0.164**	0.161**	0.071	−0.175**	−0.183**
Ti pXRF							0.842**	0.923**	−0.375**	0.381**	0.935**	0.407**
Mn pXRF								0.878**	−0.272**	0.339**	0.834**	0.251**
Fe pXRF									−0.415**	0.392**	0.903**	0.317**
Cu pXRF										−0.071	−0.330**	−0.121*
Zn pXRF											0.423**	−0.041
Rb pXRF												0.465*

Ceibal, Guatemala (r=0.294**) (Bair 2010); the butchering and meat sales corner of the plaza at the modern village of Telchaquillo (Coronel *et al.* in press); and at platform 341 at the north end of the Xtáabay feature (r=0.585**) at Xtobo, Yucatan. This platform contained 23 limestone metates and grinding stones (Anderson *et al.* 2012). These correlations between P and Zn may have an explanation in the P and Zn concentrations in crops. For example, nutrient sufficiency ranges in corn tissues at maturity have been reported for P (2500–5000 mg kg^{-1}) and for Zn (16–50 mg kg^{-1}) (Mills and Jones, Jr. 1997). Similar nutrient sufficiency ranges were reported in bell pepper and tomato. Furthermore, a ratio of 200:1 in plant tissue between P and Zn is considered critical for growth in major crops (Jones, Jr. *et al.* 1991). It is likely that plant matter was the major source of P and Zn enrichment in the plazas and household activity areas referred to above. Fe, Mn, and Cu are also micronutrients present in plant and animal foodstuffs, but Fe based minerals and pigments used by the Maya also contained trace element contaminants. The use and trade of these materials at locations separated from foodstuffs is evidenced by the significant correlations between total Fe and total Ti, Mn, Zn, Rb, and Zr in the floor of Plaza A at Cobá (TABLE 4).

The highest extractable Fe concentration in Plaza A was 50.8 mg kg^{-1} and background level was calculated at 2.9 mg kg^{-1} (TABLE 3). DTPA extractable Fe was found in high concentrations (36–46 mg kg^{-1}) at the start of Sacbe 1 on the west side of the plaza. This high concentration may be the result of modern activities by site custodians to keep the sacbe and the area around it cleared of vegetation. Elevated extractable Fe concentrations were found in samples just north of the plaza, between Structures D-8 and D-3 (41–46 mg kg^{-1}). Tourists currently park bicycles in this area. A very interesting pattern was located around El Cono/Xaibe, in the east corner of the grid. High Fe concentrations of 26–31 mg kg^{-1} surrounded El Cono/Xaibe. A likely source of extractable Fe in these areas was the modern implements used to maintain the tourist paths, to rake loose plant material, or to cut vegetation; in fact all the highest concentrations of DTPA extractable Fe are located on or close to the path and areas cleared of vegetation open for the tourists.

The distribution of total Fe, determined by pXRF, was much different than that of extractable Fe (FIG. 7A), and the correlation between the two forms of Fe was very low (r=0.190**) (TABLE 4). The crystalline forms of iron compounds are modified by years of weathering to less soluble forms (Raiswell 2011) and therefore less susceptible to DTPA extraction. The maximum total Fe concentration in

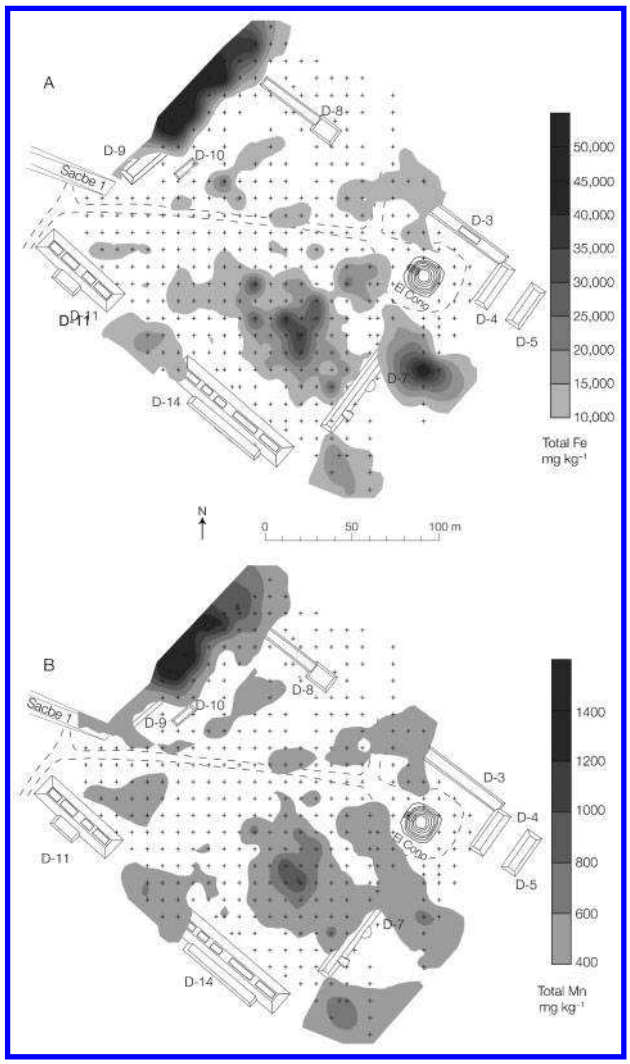

Figure 7 Concentration isopleths (mg kg^{-1}) of (A) pXRF total Fe and (B) pXRF total Mn in the floor of Cobá Plaza B.

the floor of Plaza A was 56,854 mg kg^{-1} (5.68%) and the background level was 2934 mg kg^{-1} (0.29%). These concentrations are at least three orders of magnitude greater than DTPA extractable Fe concentrations. Elevated levels of total Fe were found in front of Structure D-9 and just south of El Cono/Xaibe (FIG. 7A). In each case, high total Fe is found in floor samples beneath the forest canopy and away from areas of modern disturbance. Extractable Fe concentrations around El Cono/Xaibe and at the north end of Plaza A near the bicycle parking area likely reflect recent deposition of Fe. Total Fe in front of Structure D-9 could reflect ancient painting or market activities. High concentrations in the south quarter of the plaza could have been deposited by production or trade in mineral craft items or mineral based goods. Elevated extractable Fe concentrations have been reported in the floor of an elite workshop where pyrite mirrors were fashioned for the king's regalia at Aguateca, Guatemala (Terry *et al.* 2004). A ball of hematite was excavated at a low-status household at the same site. Sheets (2000) reported that every excavated household at Joya de Cerén, El Salvador possessed a cylinder of hematite pigment. The red pigment was apparently an important item in household activities and it is likely that such items were widely traded in the ancient Maya economy. It is apparent that trade in these mineral items were in a designated portion of the marketplace, separated from food items as reported by the conquistadores (Cortéz 1962; Feldman 1978) and as found in geochemical examinations of other plazas (Dahlin *et al.* 2007; Dahlin *et al.* 2010; Coronel *et al.* in press). High extractable Fe and low total Fe around El Cono/Xaibe are likely the result of modern iron tools used in consolidation of the structure, clearing of vegetation by machete, and raking of leaves to accommodate tourist visitation. This is the same result seen in Plaza B (FIGS. 6A, B). Similar patterns of extractable Fe associated with contemporary activities and total Fe related to activities of the past have been reported at Telchaquillo, Yucatan (Coronel *et al.* in press) and at Ceibal Plaza A (Bair 2010).

The highest levels of extractable Mn (41–50 mg kg^{-1}) appeared in the southwest corner, close to the start of Sacbe 1. Background Mn level was of approximately 5.6 mg kg^{-1} (TABLE 4). The maximum total Mn level in the plaza floor was 1573 mg kg^{-1} and the background was calculated at 182 mg kg^{-1} (TABLE 3). The distribution of total Mn (FIG. 7B) was generally aligned with total Fe (FIG. 7A), and there

Table 5 The maximum, minimum, average, standard deviation, and background levels of of Mehlich II extractable P, DTPA chelate extractable metals, and pXRF total metals in the soils and floors of the Plazas H and J of Group D at Cobá. The background concentrations of elements were calculated by averaging the 10% of the samples lowest in concentration.

	Mehlich	DTPA	DTPA	DTPA	DTPA	DTPA	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF
	P	Cu	Fe	Mn	Pb	Zn	Fe	Ti	Mn	Cu	Pb	Zn
	mg kg^{-1}											
Maximum	79.7	1.23	71.9	141.5	4.05	5.13	20633	2670	757	61	23	83
Minimum	4.8	N.D.	N.D.	N.D.	N.D.	N.D.	1004	115	30	38	N.D.	42
Average	7.9	0.32	14.2	16.1	0.99	1	6641	835	254	48	3	57
STDEV	5.4	0.17	10.6	13.2	0.5	0.67	4268	528	106	4.1	5	6.5
Background	5.3	N.D.	2	4.6	N.D.	N.D.	1799	238	103	41	N.D.	48

N.D.=not detectable.

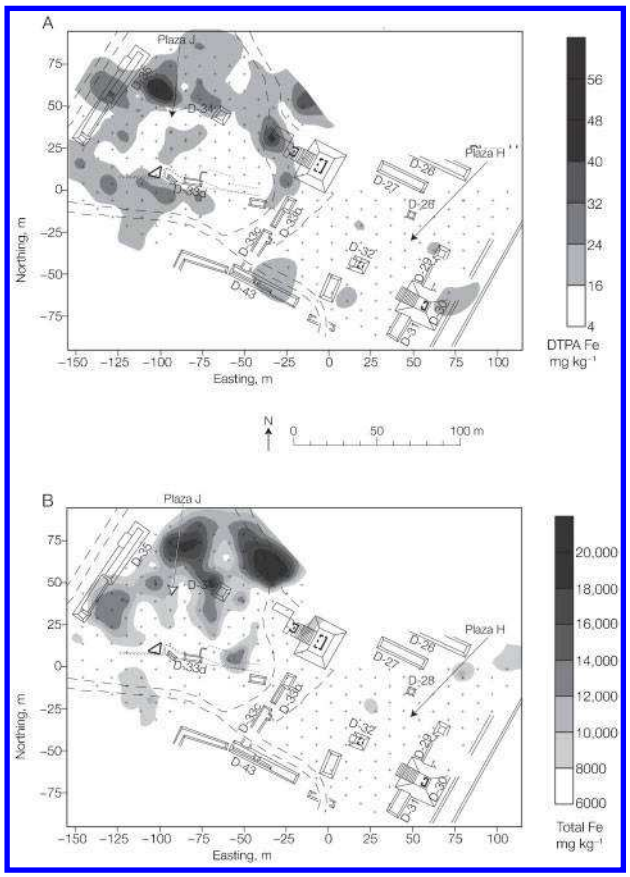

Figure 8 Concentration isopleths (mg kg^{-1}) of (A) DTPA extractable Fe and (B) pXRF total Fe in the floor of Cobá Pinturas Plazas H and J.

was a strong correlation between the two metals (r=0.878**). Extractable Cu was less than 2.6 mg kg^{-1} in the plaza floor samples but there were significant correlations with other metals including extractable Fe, Mn, Pb, and Zn and with total Fe (TABLE 4). It is likely that Cu and Mn levels were associated with mineral craft items used or traded in the plaza.

Plazas H and J, Group D

A total of 205 samples were taken from Plazas H and J (FIG. 5). The maximum, minimum, average, and background concentrations of extractable and total elements in the floor of the two plazas are listed in Table 5. Elevated P concentrations (FIG. 5A) were found in the eastern portion of Plaza H in conjunction with Structures D-29, D-30, and D- 31, with the highest concentration between the back of Structure D-30 and Sacbe 8. Evidences of high P concentration were found in front of Structure D-30 and the pattern formed a parallel line with Sacbe 8 and the three structures noted above. The linear alignment of elevated DTPA Zn in front of Structure D-30 is similar to that of the extractable P (FIG. 5B). In addition, elevated concentrations of extractable Zn were significantly correlated with extractable P in Plazas H and J (TABLE 6) (r=0.426**). Correlations between P and Zn were reported in previous studies

Table 6 The regression matrix of Mehlich extractable P, pXRF total elements, and DTPA chelate extractable elements in the samples of Plazas H and J of Group D at Cobá. Correlation significance is represented by * at p<0.05 and ** at p<0.01.

		DTPA	DTPA	DTPA	DTPA	DTPA	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF	pXRF
n=236		Cu	Fe	Mn	Pb	Zn	Ti	Mn	Fe	Cu	Zn	Rb	Zr	
Mehlich	P	0.035	−0.223**	0.094	0.123	0.426**	−0.190	0.060	−0.193**	−0.203**	−0.075	−0.249**	−0.385**	
DTPA	Cu		0.377**	0.259**	0.161*	0.289**	0.351**	0.318**	0.339**	0.321**	0.290**	0.335**	−0.027	
	DTPA		Fe	0.149*	0.066	0.016	0.353**	0.195**	0.341**	0.412**	0.300**	0.361**	0.373**	
			DTPA	Mn	0.268**	0.339**	0.058	0.202**	0.056	0.061	0.004	0.038	−0.128	
				DTPA	Pb	0.343**	0.136*	0.246**	0.132	−0.077	0.120	0.039	−0.264**	
					DTPA	Zn	−0.103	0.091	−0.111	−0.208**	0.110	−0.191	−0.437**	
						pXRF	Ti	0.749**	0.989**	0.378**	0.821**	0.943**	0.259**	
						0.770**	0.228**	0.598**	0.674**	−0.100				
								pXRF	Fe	0.381**	0.820**	0.953**	0.274**	
									pXRF	Cu	0.395**	0.451**	0.420**	
										pXRF	Zn	0.801**	0.231**	
											pXRF	Rb	0.466**	

of marketplaces (Dahlin *et al.* 2007). The linear patterns of P and Zn suggest a row of perishable food stands in this area.

Both extractable Fe and total Fe were found in elevated levels around Structures D-35 and D-34 of Plaza J (FIGS. 8A, B, respectively). The maximum DTPA extractable Fe level in Plazas H and J was 56 mg kg^{-1}, while the maximum total Fe was 20,633 mg kg^{-1} or 2.06% of the total soil (TABLE 6). Elevated levels of extractable Fe could be attributed to modern disturbances. The pattern of elevated extractable Fe correlated with leaf litter piles. Metal rakes and machetes were the main implements in clearing spaces around the structures for tourist activity. The Fe not extracted by DTPA can be attributed to the crystalline forms of Fe compounds that have been modified by weathering over long periods of time. This crystalline Fe is less soluble; therefore DTPA extraction will extract only a fraction of the total Fe (Raiswell 2011). High concentrations of total Fe in some portions of the plaza are possible indications of ancient activities in those areas. There were significant correlations between each of the extractable and total concentrations of Cu, Fe, Mn, and Zn in the plaza floor samples (TABLE 6). This suggested the use of mineral pigments and ores at specific locations in Plaza J where levels of both extractable and total Fe were elevated (FIG. 8).

In sum, accumulations of P and Zn in Plaza H suggest food service and/or preparation/disposal in a linear pattern that we might expect to characterize a row of food stands at a marketplace. Due to a lack of permanent market features, the intensity and frequency of marketing in Plaza H would have been low. Plaza H's location also makes it a good candidate for a marketplace. It is located in the southernmost portion of Cobá's Gran Nivelación (FIG. 2) where Sacbeob 30, 10, and 8 converge. These sacbeob extend into the eastern and southern residential areas of Cobá, therefore making the Pinturas area (Plazas H and J) easily accessible. At the same time, ceramic, architectural, and art historical evidence discussed above suggest that the main period of occupation for this part of the site was the Postclassic. Although commerce may have increased in the Northern Maya Lowlands during the Postclassic, Cobá as a whole had a much smaller population in the Postclassic period, thus weakening the demand for a permanent marketplace. Nevertheless, Plazas H and J remain good candidates for occasional marketplaces because the noteworthy concentration of Postclassic temples and altars would have made this area an important destination for pilgrims. A critical mass of people congregating for ceremonial purposes makes for an excellent opportunity to buy and sell goods.

Conclusions

Cobá was one of the most important cities of the Late and Terminal Classic periods, and its influence extended through the network of sacbeob that converge at the site. That Cobá had a large population and was a major urban center serve as contextual lines of evidence (Hirth 1998) that it had a marketplace. This paper adds evidence to this configurational argument. Distributional evidence would greatly strengthen the argument but collecting such evidence requires many additional years of research. Of the several plazas that could be considered candidates for marketplaces at Cobá, four were tested in this project: Plaza B, and Plazas A, H, and J in Group D. The latter two plazas had their major occupation in the Postclassic period and therefore provide an opportunity to test for later marketplaces. Following the three lines of evidence—accessibility, market stall architecture, and geochemical signatures—used in the configurational approach to identifying markets, our results show that Plaza A has the strongest case of having been used as an ancient market (among other things).

We argue that Plaza A was the location of the kind of low intensity marketing characteristic of the pilgrimage fair model. In this model, markets occur in conjunction with ritual pilgrimages or religious ceremonies that occur with limited frequency. Thus, the traces of marketing should be light and they should be interconnected with evidence of other activities, such as large ceremonies. The data from Plaza A closely match these expectations. With regard to market stall architecture, there should be no traces of such architecture because the marketing would have occurred infrequently in this plaza, which means that stalls, if they were built, would need to be packed up and removed so that the space could also be used for other purposes. Indeed, no traces of permanent market stalls were found in Plaza A. With regard to geochemistry, chemical concentrations should be low but discernible. This is exactly the pattern found in Plaza A: Although the concentrations of extractable P were low ($<$14.7 mg kg^{-1}) the spatial distribution of extractable P and Zn exhibited a marketplace pattern. In terms of accessibility, the pilgrimage fair, which combines both ceremonies and marketing, should take place in a large plaza that is centrally located, easily entered, linked to the rest of Cobá and beyond, and associated with ritual architecture. This is exactly the case with Plaza A, which is large and well bounded but has six entry points, most of which are more than 30 m wide. The plaza has a 14 m tall monumental structure—el Cono—that is at the point of convergence of several important sacbeob. Given the convergence of both local and regional sacbeob and the massive size of

nearby temples (such as the 42 m high Ixnoja/Nohoch Mul located 150 m to the northeast), Plaza A at Cobá is one of the best candidates in the Maya area for a pilgrimage destination. In addition, there was public access to an important water reservoir just north of Plaza A. These characteristics, plus the geochemical distribution of extractable elements in association with large and small-scale architecture, suggest that marketplace activities occurred at this plaza. A pattern of elevated P, Mn, and Zn in the western portion of the plaza suggests that activities of medium intensity occurred in that area. The terminus of Sacbe 1 and the presence of El Cono/Xaibe within Plaza A suggested a location where vendors would have exhibited their merchandise for people coming and leaving the site through Sacbe 1.

Plaza H shows some of the same evidence for marketing as Plaza A (central and accessible location, linear patterning of P). This is an intriguing conclusion given that the buildings around the plaza date to the Postclassic period. Furthermore, Plaza H, like Plaza A, has ritual architecture in the form of temples (Structure D-33 and D-30). Therefore, if we are correct in inferring marketing at Plaza H, such marketing would also have been part of festivals and ceremonies. Since Cobá's population was much lower in the Postclassic, we suggest buyers came to Plaza H from well beyond Cobá for pilgrimage fairs in the original sense suggested by Freidel (1981).

In contrast, our data obtained in the study do not suggest any evidence that Plaza B was a place where marketplace activities occurred. There are few sacbeob that converge at this plaza or near it and no evidence of market stalls. As stated by the archaeologists, this plaza was most likely used for ceremonial services (Folan *et al.* 1983; Thompson *et al.* 1932). Phosphorus distributions within Plaza B do not show a pattern of linear, parallel concentrations that may represent ancient anthropogenic activities, but rather modern activities of sweeping and cleaning organic material in the area, related to the tourism at the site. We also believe that the extractable Fe concentrations on the cleared and raked eastern portion of Plaza B, the area surrounding El Cono/Xaibe, and the terminus of Sacbe 1 in Plaza A, and select locations in the Plazas H and J were related to modern anthropogenic activities of raking organic debris and cutting vegetation using machetes rather than to ancient activities by the Maya.

The present study provides further evidence that human activities, both past and present, leave identifiable traces imprinted in the soil chemistry, and these signatures can aid in the interpretation of archaeological sites. Regarding ancient activities, the evidence from Plaza A and Plazas H and J suggest that Cobá contained several spaces that were intermittently used as markets and that marketing was both physically and conceptually embedded in broader political and ritual structures. We doubt that marketing was restricted to these two locales and imagine and there were several other spaces that occasionally hosted markets. It is possible that Cobá had a single large space dedicated entirely to marketing, although no such market was located in the most likely spots. Until such a market is found, we retain a model in which the distribution of goods from producers to consumers occurred in many forms at many places. In spite of such a decentralized outlook, the times and places of markets would not have been totally unpredictable, thus enabling Cobá's leaders to sponsor, participate in, regulate, or otherwise use markets to their advantage (Masson and Freidel 2012: 460).

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